Determination of boundary conditions for passive schools : impact on heating and cooling demand

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1 Introduction

The Passive House standard is originally developed for dwellings in a moderate climate. This standard is extended to school buildings aiming a very low energy consumption and a high thermal comfort. In Flanders (Belgium), as of December 7, 2007, the criteria for Flemish passive school were set forward by the government:

- annual net heating demand ≤ 15 kWh/(m².a)
- annual net cooling demand ≤ 15 kWh/(m².a)
- n_{50} ≤ 0,6 air changes per hour
- maximum E-level = 55 (energy performance as defined by EPB)

These criteria show strong resemblances to the performance criteria as set for residential passive buildings. However, the boundary conditions for schools differ strongly from the well known characteristics of residential buildings. In comparison, schools typically have a discontinuous user profile, higher occupancy rates, higher internal heat gains and ventilation flow rates and a large percentage of glass surface. Considering the significant influence of these characteristics on the heating and cooling demand, a set of boundary conditions needs to be defined to guarantee a uniform and objective evaluation of the design of all passive schools in Flanders. Implementing this set of boundary conditions in the existing monthly calculation method PHPP, the impact of these characteristics on the energy demand for heating and cooling is studied. In addition, the results of these calculations are compared to the results of dynamic building simulations in TRNSYS.

2 Methods

A list of boundary conditions is developed to evaluate the performance criteria of the Flemish passive schools based on the existing European (EN 12464, EN 13779, EN 15251, EN ISO 7730, EN ISO 13790), Belgian (NBN B 06-002), German (DIN V 18599) and Dutch

(NEN 1089) standards concerning energy performance, ventilation and comfort. Furthermore, the boundary conditions as set for German passive schools [Kah,2006] are used as a reference. The boundary conditions are implemented in the Passive House Planning Package [PHI,2007] software to evaluate the energy performance level. This software tool is partially based on EN ISO 13790 (CEN, 2008). The building is considered as one zone. The heating and cooling demand are calculated for each month. The impact of the new boundary conditions is determined by comparing the original calculations with the results of the calculations after the implementation of the newly defined boundary conditions. The results of PHPP are compared to dynamic simulations in TRNSYS [Klein et al., 2004]. This simulation program subdivides the building in various zones. For each zone, the heating and cooling demand are calculated each time step, in this case one hour. To make an accurate comparison, the input data and boundary conditions in both tools (building element area, U-values, internal heat gains, weather data, etc.) are set identical.

Figure 1. South & South-West Facades (evr-architects)

This analysis is applied on a pilot school project, a nursery school in Etterbeek (Brussels, Belgium). The building is a design of evr-Architects, engineering office 3E (energy), Fraeye and Partners (structural engineering) and engineering office Stockman (HVAC). The school building (Figure 1) consists of 2 floors including 10 class rooms, a polyvalent room which is used as a play ground and canteen, sanitaries, a hall and some store rooms. Based on the different user profiles of the polyvalent room and the class rooms, the building is split into 2 different zones. The outside cavity sheet consists of a wooden structure filled with 28 cm glaswool. The inside cavity sheet and internal walls are made of sand-lime bricks. The solar heat gain coefficient g of the windows is 0,60. An overhang is provided at the South-West and West facade as an external solar shading devices (Figure 1). An airtightness level of n_{50} = 0,6 air changes per hour is assumed. Balanced mechanical ventilation is provided by two air handling units. The heat load is covered by an air heating system. The air, preheated by an air-to-air heat recovery (η = 85%), is heated by a condensing boiler. Additionally, floor heating is provided in the polyvalent room [Achten, 2009].

3 Determination of the boundary conditions

3.1 Weather data

The Global Meteorological Database Meteonorm (Meteotest, 2003) creates synthetic hourly weather data, based on the climatological normals of 1961-1990 of the meteorological station Uccle (Belgium). These hourly data are converted into monthly based data for the input in PHPP to make an accurate comparison with the calculations in TRNSYS.

3.2 Monthly mean indoor temperature

The indoor temperature, θ_i, during occupancy is determined by the purpose of the room, based on the European standards EN ISO 7730:2005 and EN 15251 (Table 1. Overview of boundary conditions). In order to take into account the intermittent user profile of the school, the mean indoor temperature, $\theta_{i,m}$, is determined by lowering the operative indoor temperature during occupancy by $\Delta\theta_i$ = 0,6 °C as specified in German guidelines [Kah, 2006]. A monthly average indoor temperature of 19,24°C is calculated for the whole school building. For the calculation of the cooling demand, a monthly average temperature of 24°C, based on DIN V 18599, is used. No reduction of the operative temperature due to the absence during the nights and weekends is considered.

3.3 Treated floor area

The treated floor area is calculated as described in NBN B 06-002. The treated floor area of this school building is 932 m².

3.4 Occupancy and ventilation rates

The occupancy rates are based on NBN EN 13779 (Table 1). Moreover, in accordance with the Flemish EPBD requirements, a moderate indoor air quality (IDA3) is required, raised in relation to the activity level and the age of the occupant (EN 13799, Passivhaus Institut) (Table 1). [Kah,2006] advises a discontinuous ventilation schedule according to the user profile. In this case study, both handling air units are controlled by a time schedule according to the user profile of the school. Due to the intermittent ventilation schedule, each room must be pre-ventilated during 1 hour before the start of school. According to NBN EN 15251, 2 air changes per hour are necessary to guarantee a sufficient indoor air quality.

3.5 User profiles

A typical user profile is defined for nursery schools. In Flanders, lessons are evenly spread over five days from Monday to Friday from 8h25 till 15h45. Wednesday afternoon is free. A school year counts a total of 99 days off: 5 days in January, 3 at the end of February, 2 at the beginning of March, 12 in April, 3 in May, 1 in June, 3 in October, 2 in November and 6 in December. During a 2 months summer holiday (July and August) schools are closed. For classrooms, diminished occupation of 95% is assumed as sport is taught in the gymnasium.

3.6 Internal heat gains

An overview of the sensible heat gain by occupants, IGH_{occ}, is listed in Table 1. These values are based on DIN V 18599 and adapted to the Flemish school system. The area specific heat gain due to appliances, IGH_{app}, is based on the stated default value for a variety of rooms in DIN V 18599. For energy calculations, the internal heat gain of lighting is assumed 2 W/(100 lux.m²). The required illuminance of each room is specified in Table 1, based on EN 12464-1.

	θ_i [°C]	$Q_{ventilation}$ [m³/h]	IGH_{occ} [W/pers]	IGH_{app} [W/m²]	Illuminance [lux]
Classrooms	20	22	60	1	300
Canteen	20	22	60	1	300
Office	20	29	80	10	500
Teachers' room	20	29	80	2.5	500
Play ground	18	33	80	-	300
Circulation area	20	-	-	-	100
Store room	20	-	-	-	-
Toilets	20	-	-	-	200

Table 1. Overview of boundary conditions

4 Impact on the energy demand for heating and cooling

4.1 PHPP

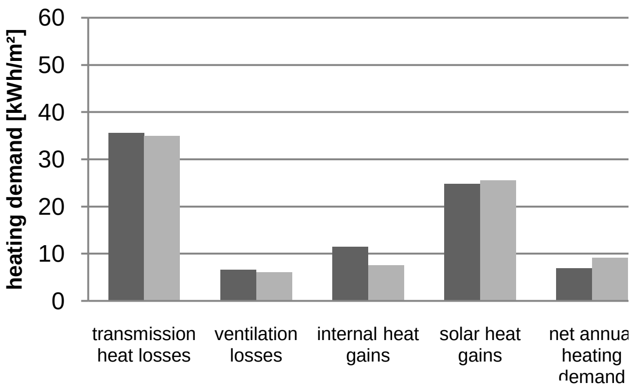

Figure 2. Impact on heating demand (PHPP)

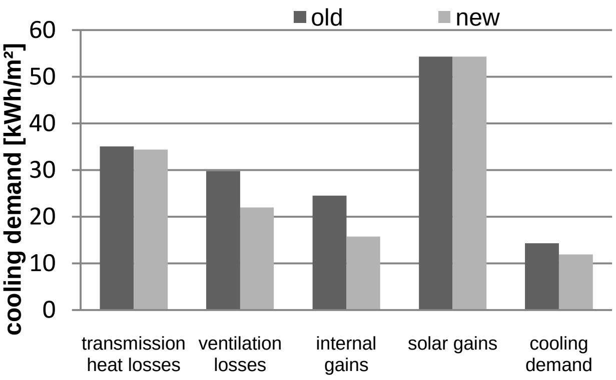

Figure 3. Impact on cooling demand (PHPP)

Figure 2 and Figure 3 show the impact of the new set of boundary conditions on respectively the net annual heating and cooling demand in PHPP as well as the specific heat losses and the specific heat gains. In case of heating (cooling) demand calculation, the heat gains (losses) are multiplied by the utilization factor, ŋ.

An increase of the heating demand of 29,3 % is noticed as the net annual demand raised from 7 kWh/(m².a) up to 9 kWh/(m².a) after implementation of the boundary conditions. At first, a significant decrease of 36% of the internal heat gains is found. Originally, a monthly average value of 2,8 W/m² was used for calculating the heating demand [Kah,2006]. Implementing the boundary conditions as described in Table 1 and taking into account the user profiles and the control system of the lighting devices, a monthly average value for internal heat gains of 1,80 W/m² is found. Furthermore, Figure 2 shows a small decrease of the ventilation losses. This is caused by the implementation of a realistic user profile which takes into account holidays. Finally a slight decrease of the transmission losses is noticed, caused by the newly defined indoor temperature. As user-behaviour has no effect on the energy transport through glazed surfaces, the new boundary conditions have no impact on the solar heat gains. A decrease of 15,9 % of the cooling demand is noticed. Similar to the calculations of the net energy demand for heating, a decrease of the ventilation losses and internal heat gains is found. Furthermore, a decrease of the monthly mean indoor temperature of 25°C to 24°C causes slightly smaller transmission losses. The strongest reduction however, is due to the exclusion of the summer holiday period, July and August.

4.2 Comparison PHPP-TRNSYS

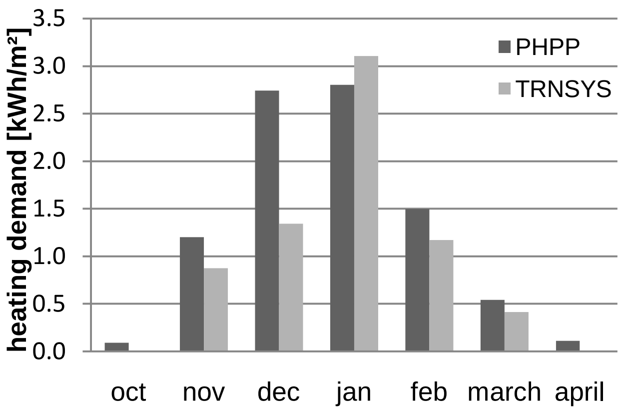

Figure 5: Comparison heating demand

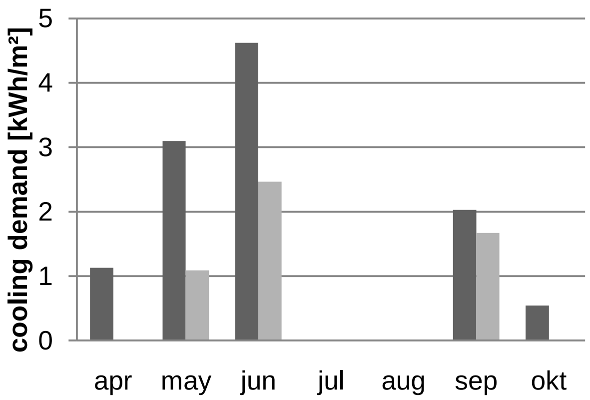

Figure 4: Comparison cooling demand

The annual heating demand equals 6,9 kWh/(m².a) in TRNSYS and 9,0 kWh/(m².a) in PHPP. Figure 5 compares the monthly heating demand between PHPP and TRNSYS during the heating season (October-April). Both calculation methods show a comparable graph, except for December and January. Due to 2 weeks vacancy during Christmas Holiday, the indoor temperatures decrease which lead to an energy need for heating. As the set point temperature for heating (12°C) in TRNSYS is only reached by the last day of December, the impact of the extra heating is only noticed in January. In December on the other hand, the energy demand for heating is assessed higher by the monthly calculation method PHPP as the internal gains are averaged over the whole month instead of only the period of occupancy.

The annual cooling demand equals 5,25 kWh/(m².a) in TRNSYS and 11,92 kWh/(m².a) in PHPP. Figure 4 compares the monthly cooling demand between PHPP and TRNSYS during the cooling season (April-October). The two graphs as shown in Figure 4 are comparable but the results are assessed significantly higher by PHPP.

5 Discussion and conclusion

The new set of boundary conditions for passive schools in Flanders results in an increase of heating demand and decrease of cooling demand in PHPP for the nursery school in Etterbeek (Brussels). Furthermore, this heating and cooling demand is overestimated in PHPP compared to the dynamic simulations in TRNSYS. This conclusion corresponds to [Kalema, et al.,2008; Sofic & Bednar, 2007; Breesch et al., 2010] agreeing that significant difference exists between the prediction for heating and cooling demand between dynamic simulations and the simplified calculation methods based on EN ISO 13790. By implementing realistic boundary conditions, the newly calculated heat losses and heat gains in PHPP correspond better to the results in TRNSYS. Nevertheless, the difference between the results for the heating demand in PHPP and TRNSYS is raised by 2 kWh/(m².a). This is caused by the significant overestimation of the internal heat gains in the originally calculations (see 4.1). As both the original and the new monthly calculation in PHPP use a similar (47% respectively 48%) utilization factor, η, the overestimation of the heat gains causes a lower net annual heating demand and makes the original calculations appear to correspond better to the results in TRNSYS. Similar conclusion counts for the cooling demand. On the other hand, excluding the summer holiday for calculation of the cooling demand, the results of the new calculation correspond better to the results in TRNSYS.

6 Acknowledgement

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